Constraints on chameleons and axion-like particles from the **GammeV** Experiment

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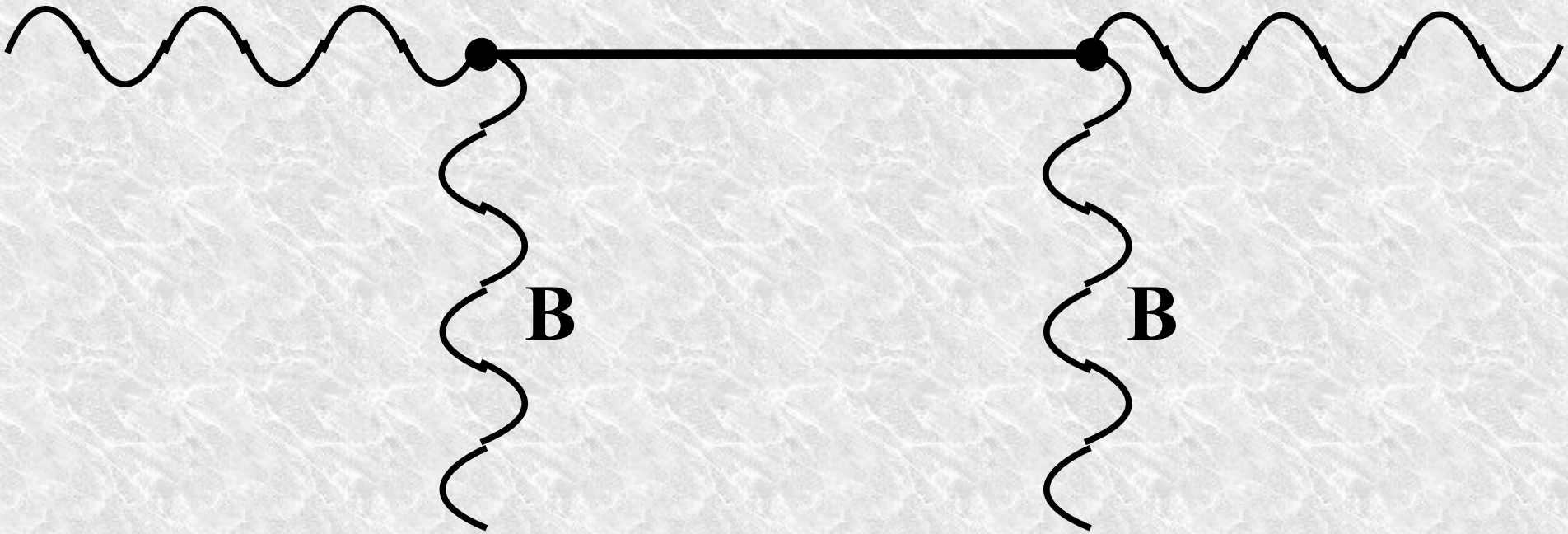
Outline

- GammeV – Axion
  - Light-shining-though-wall concept
  - GammeV results
- GammeV – Chameleon
  - Chameleon background information
  - Particle-in-a-jar concept
  - Chameleon results
- Future GammeV projects

Axions, the Other Dark Matter

Pseudoscalar coupling to two photons.

$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}\widetilde{F}^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{B})$$



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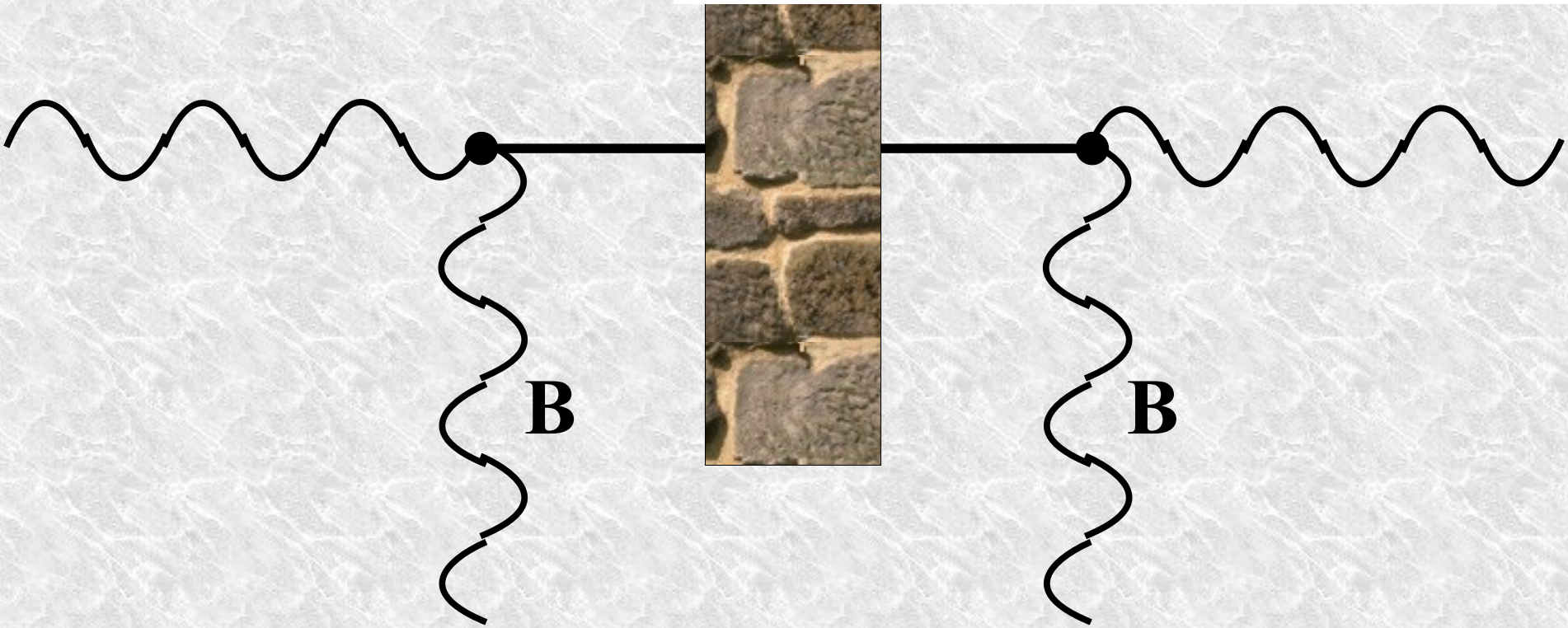

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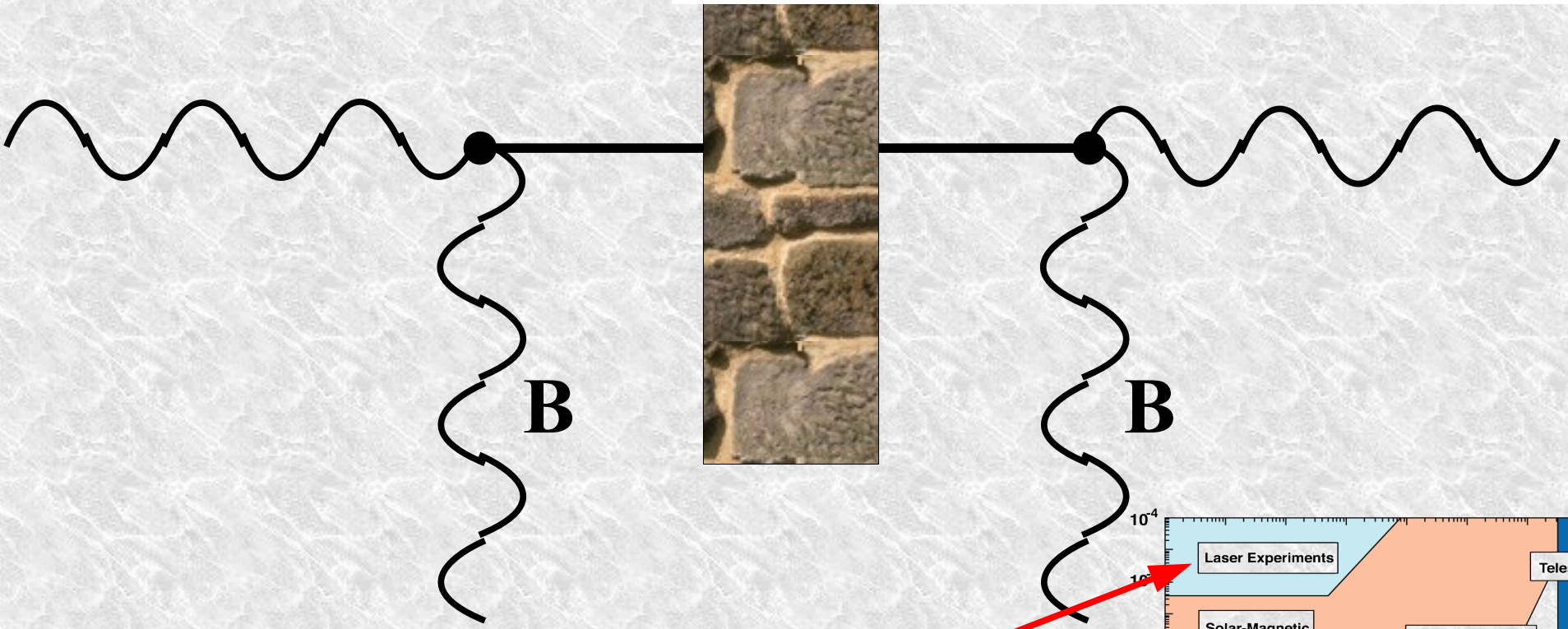
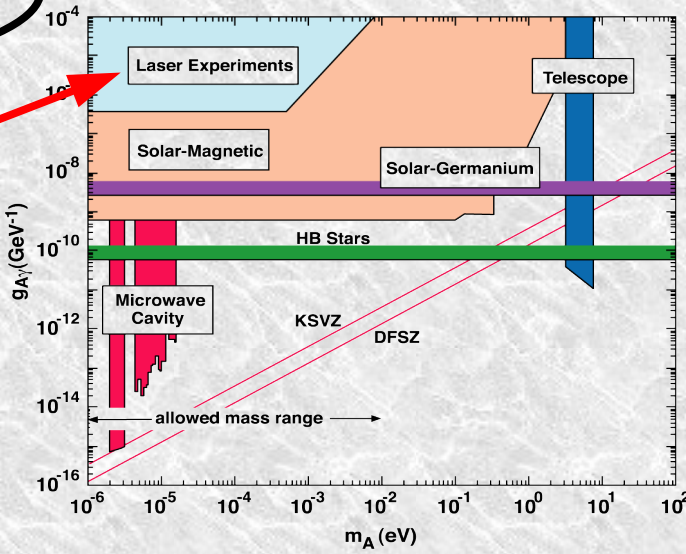


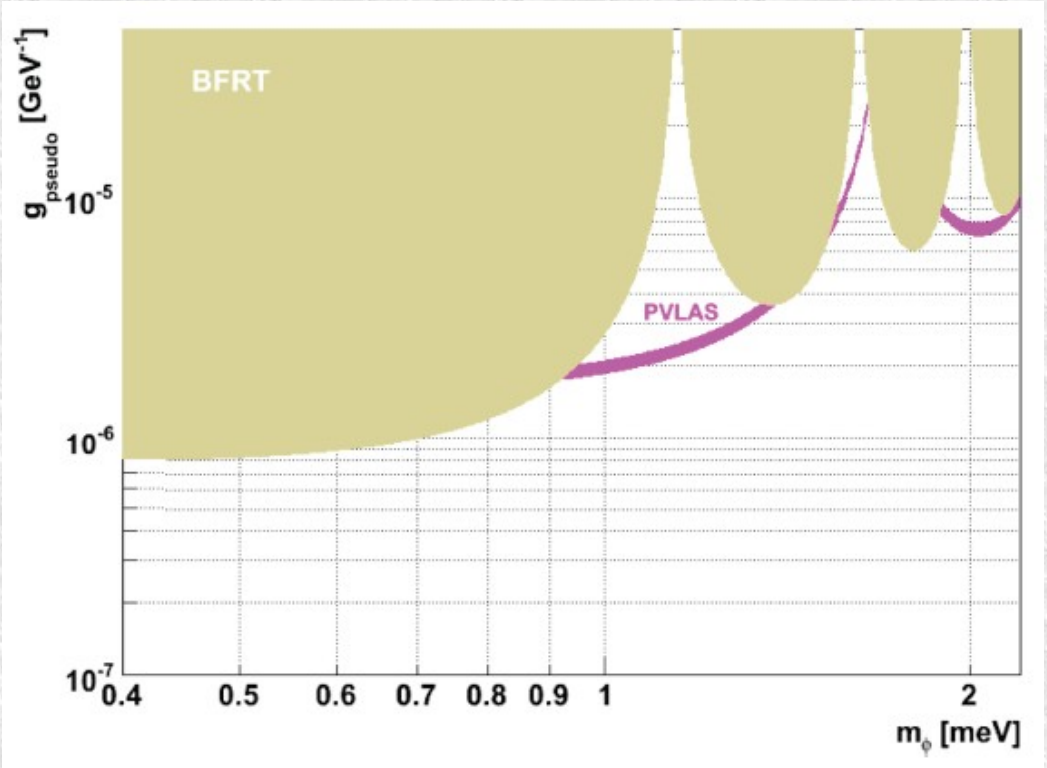
This process gives the "laser"
experimental results.
(BFRT Experiment)



GammeV – Axion: Motivation

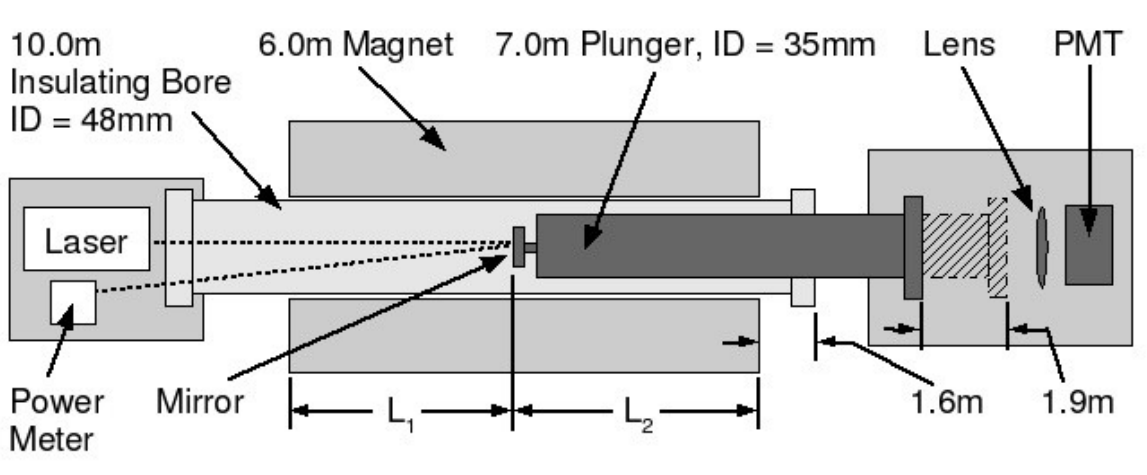
$$P_{\gamma\to\gamma} \simeq \frac{16B^4\omega^4 g^4}{m_\phi^8} \sin^2\left(\frac{m_\phi^2 L_1}{4\omega}\right) \sin^2\left(\frac{m_\phi^2 L_2}{4\omega}\right)$$

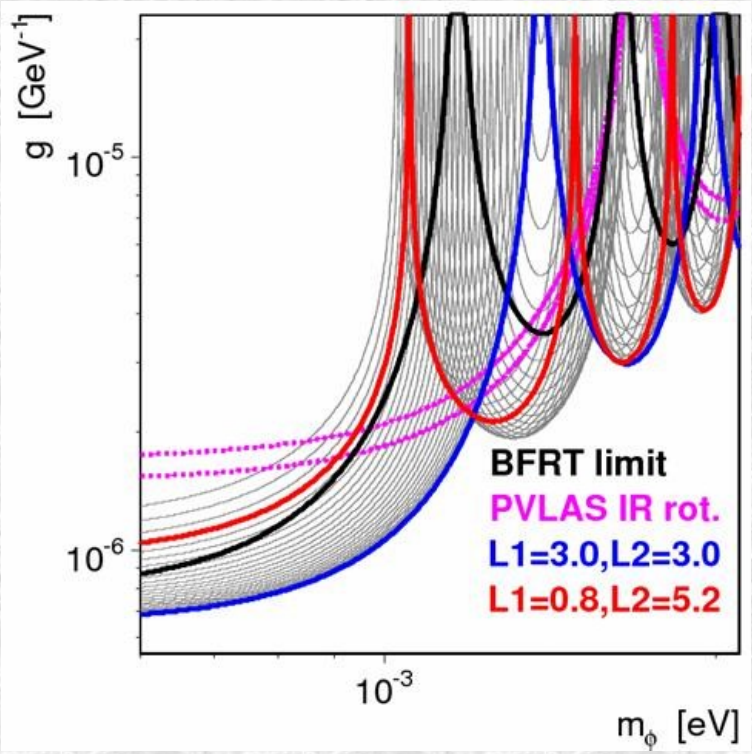
- Fixed magnet length yields regions where sensitivity is reduced
- PVLAS parameters lie in a region of diminished BFRT sensitivity



GammeV – Axion: Concept

- Plunger design allows us to adjust the lengths of the magnetic field regions
- Pulsed laser improves signal-to-noise ratio (~200)

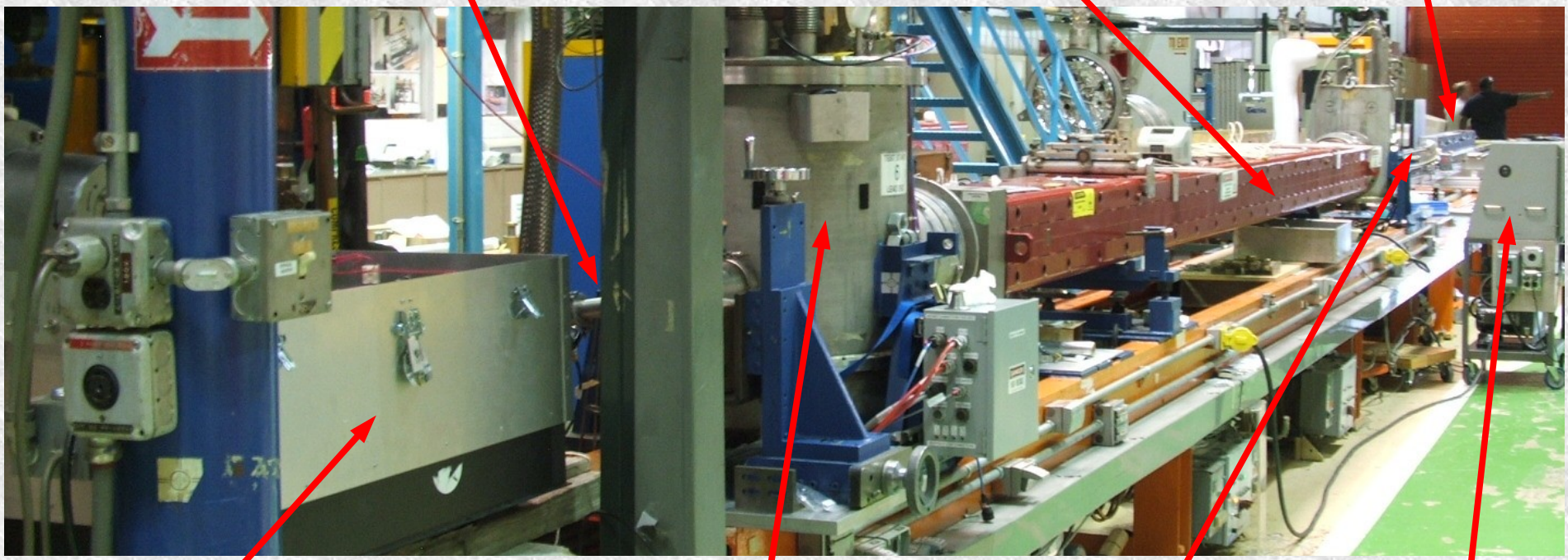




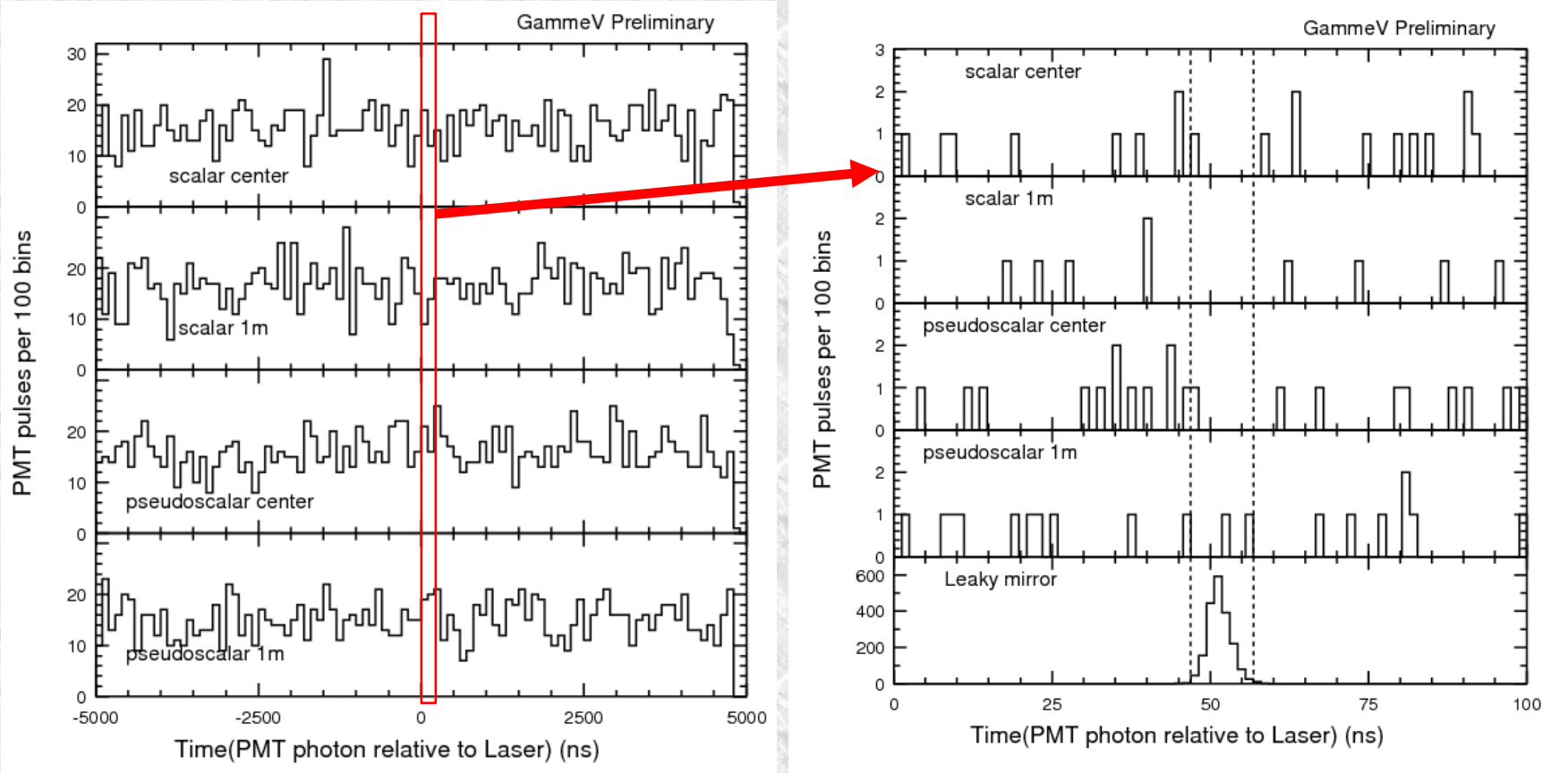
3-sigma limits after 5 hours

- Taking data in two different configurations allows us to probe the entire region surrounding the PVLAS signal

GammeV – Axion: Realization



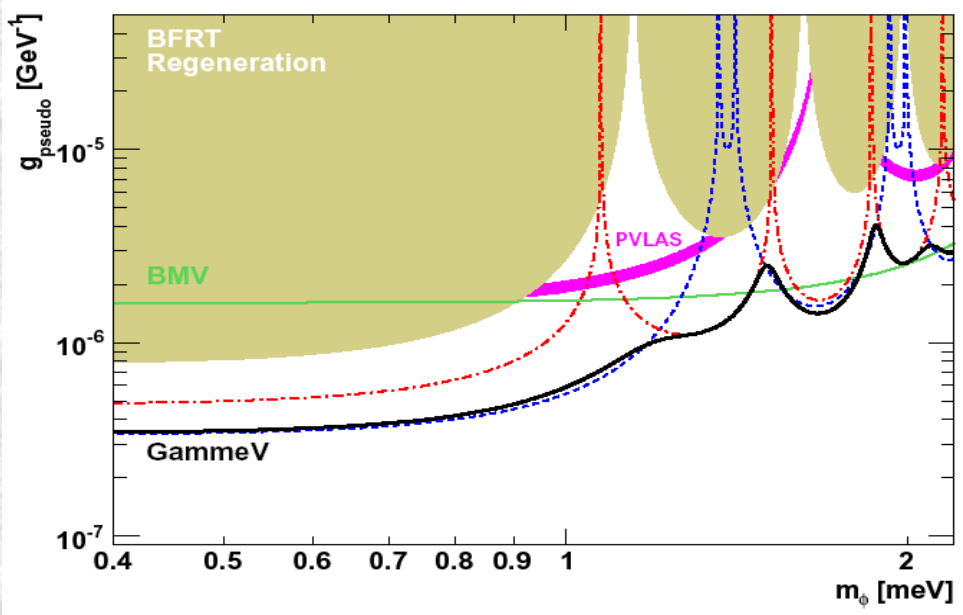
GammeV – Axion: Results



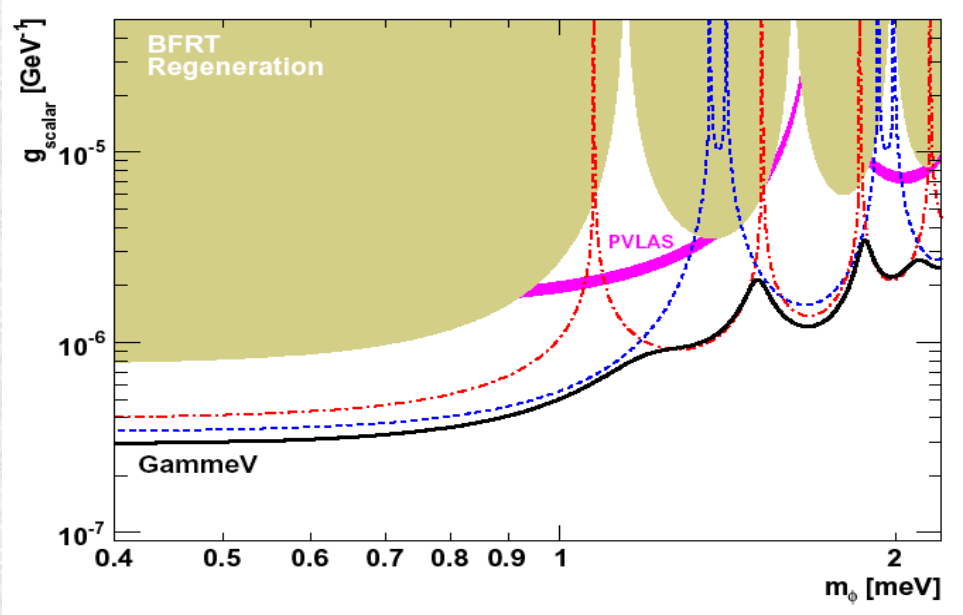
Spin	Position	# Laser pulse	# photons	Expected Background	Signal Candidates
Scalar	Center	1.34M	6.3e23	1.6	1
Scalar	1 m	1.47M	6.4e23	1.7	0
Pseudo	Center	1.43M	6.6e23	1.6	1
Pseudo	1m	1.47M	7.1e23	1.5	2

GammeV – Axion: Results

Pseudoscalar Limits



Scalar Limits

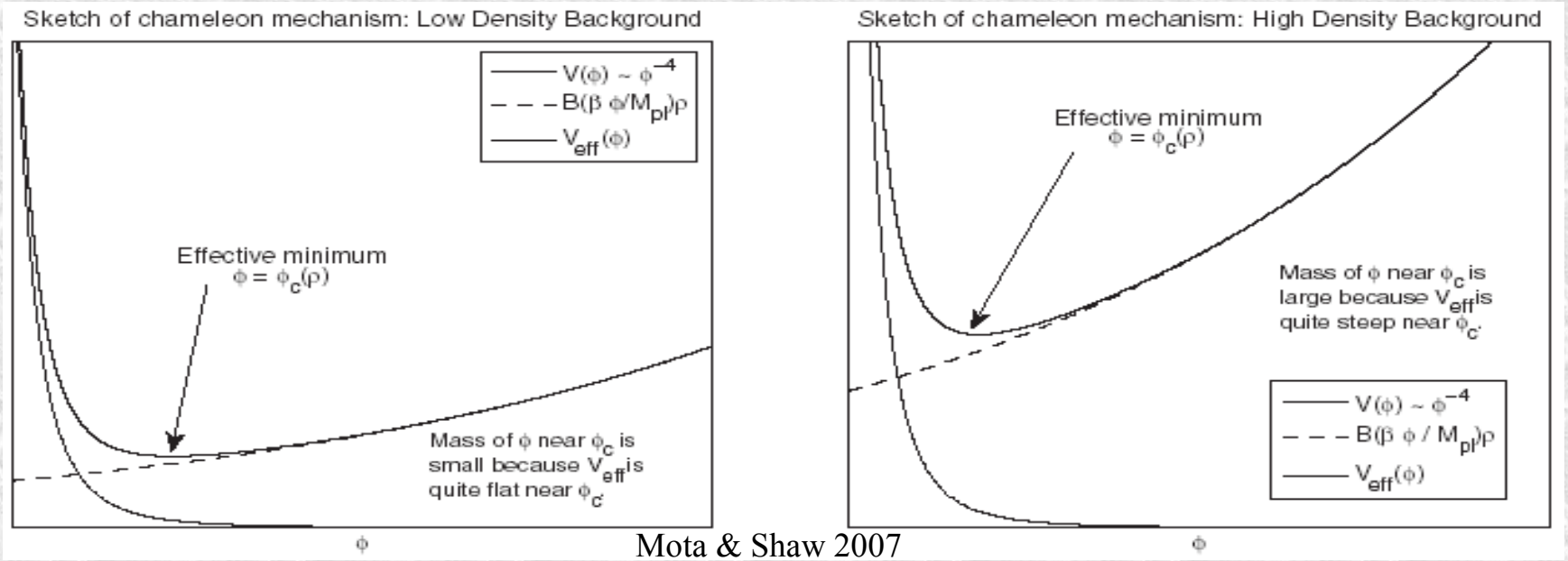


Tan region: BFRT 3-sigma exclusion
Pink region: PVLAS 3-sigma detection
Green line: BMV 3-sigma exclusion

Red line: **GammeV** 3-sigma exclusion center position
Blue line: **GammeV** 3-sigma exclusion edge position
Black line: **GammeV** 3-sigma combined limit

Chameleon Particles

- New scalar field with nontrivial potential and coupling to the energy–momentum tensor
- Mass is a strong function of the local energy density
- Hides the axions of string theory (Khoury/Weltman)
- Evades star cooling limits and tests of gravity



Mota & Shaw 2007

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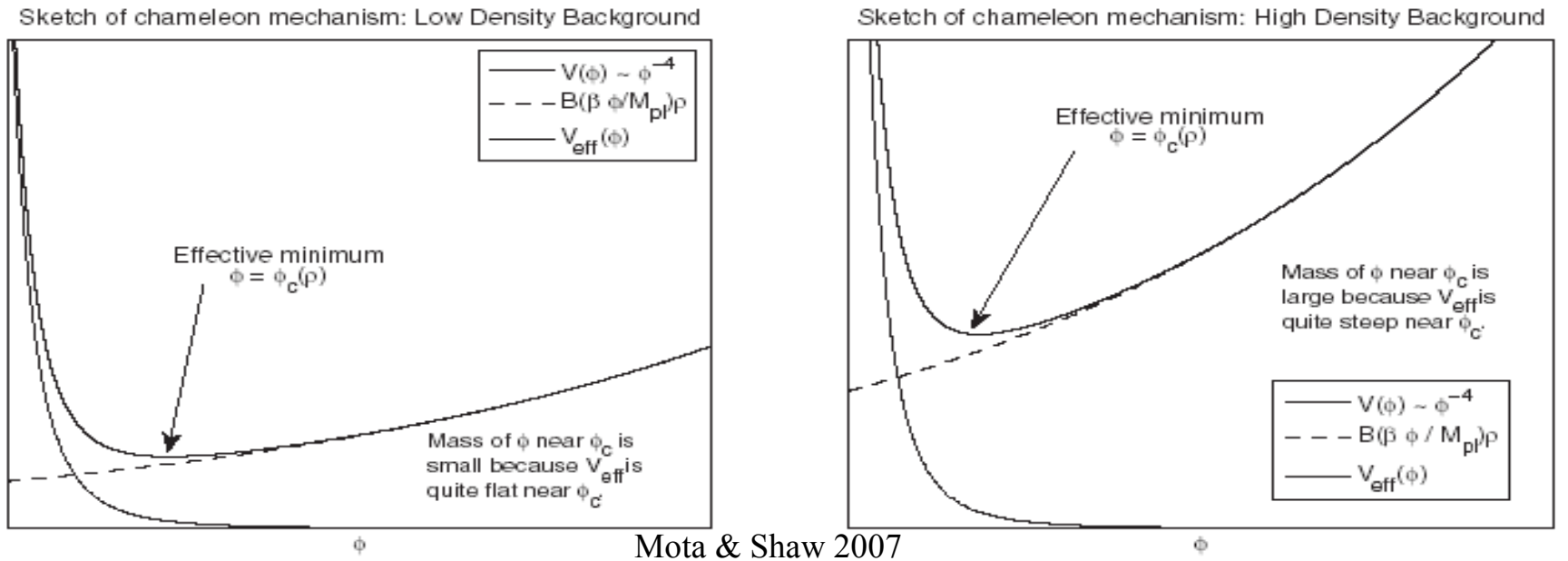

Mota & Shaw 2007

NB: The simplest models predict $m_{\text{eff}} \sim \rho^{\alpha}$.

GammeV – Chameleon: Concept

Strong matter effects cause the warm bore walls and vacuum windows to act like fully reflective mirrors.

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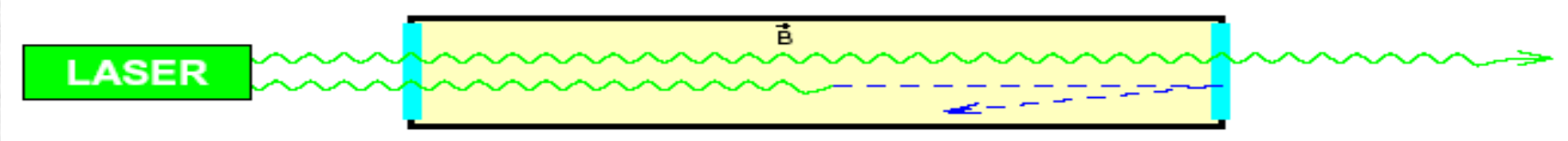

The laser shining into the cavity will fill the “jar” with chameleons.

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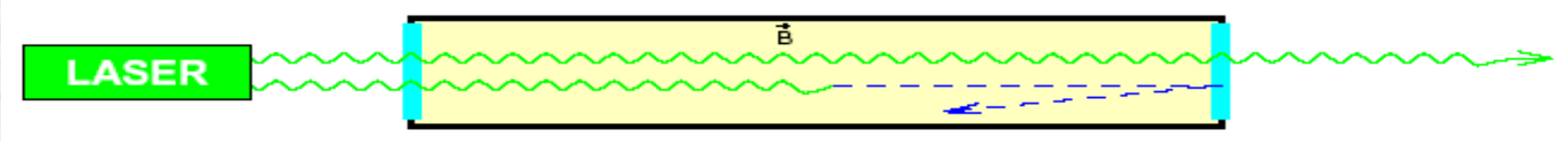

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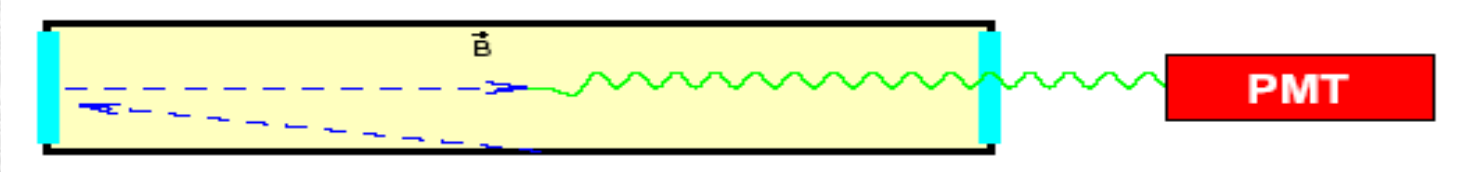
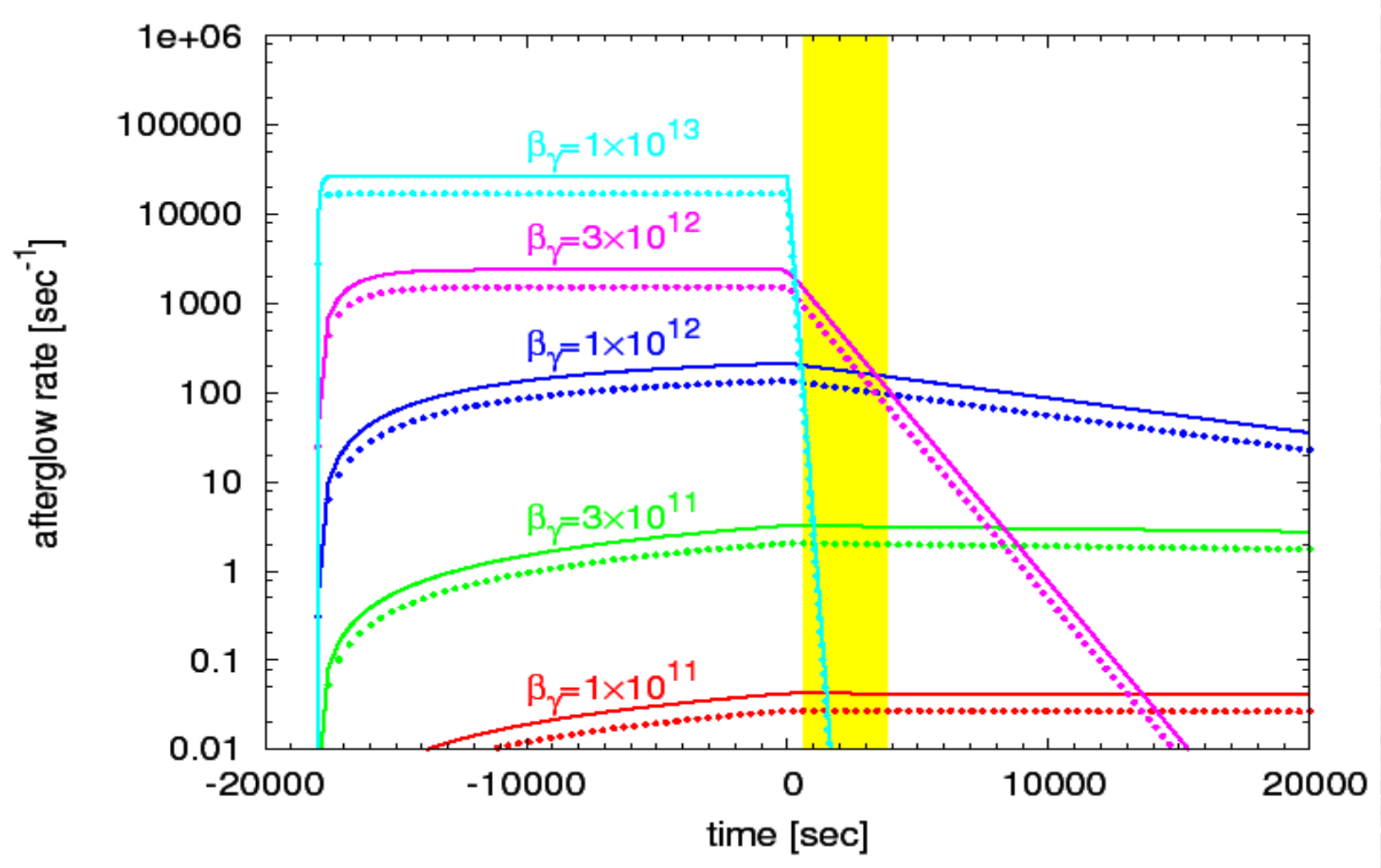


After the jar is filled and the laser is turned off, you should see an afterglow as the chameleons reconvert to photons and escape.

GammeV – Chameleon: Concept



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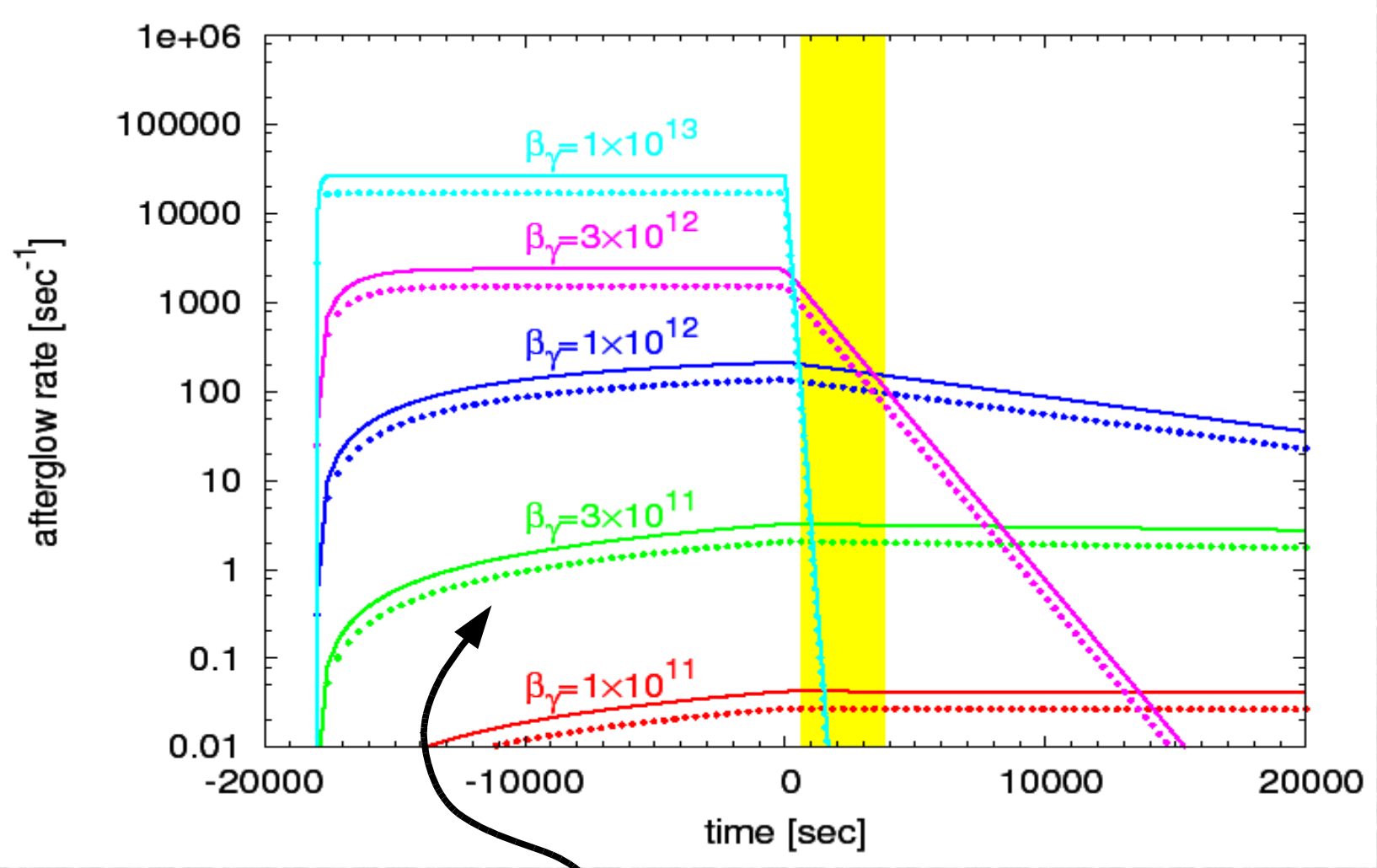
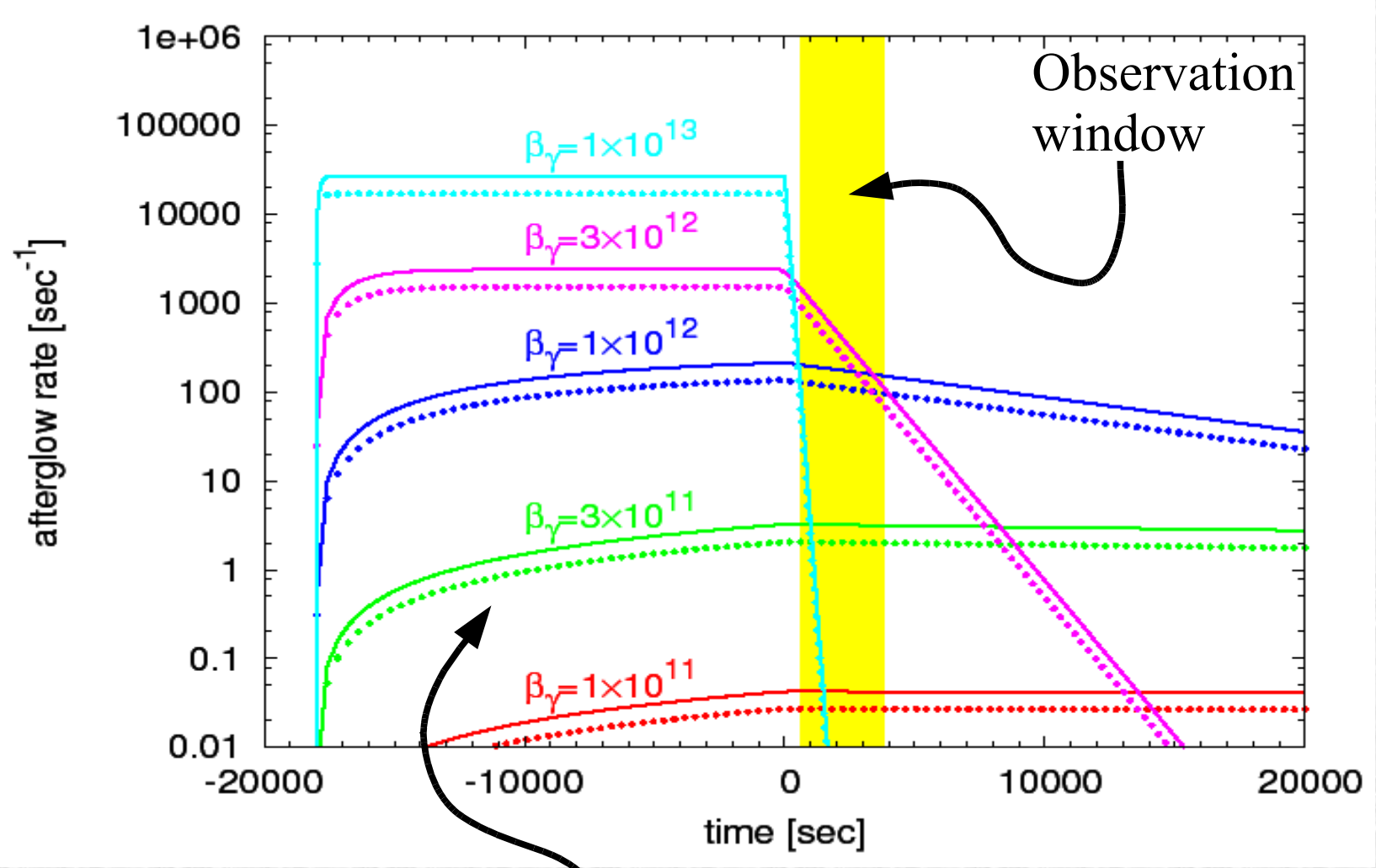


Chameleon population builds during the filling stage

GammeV – Chameleon: Concept



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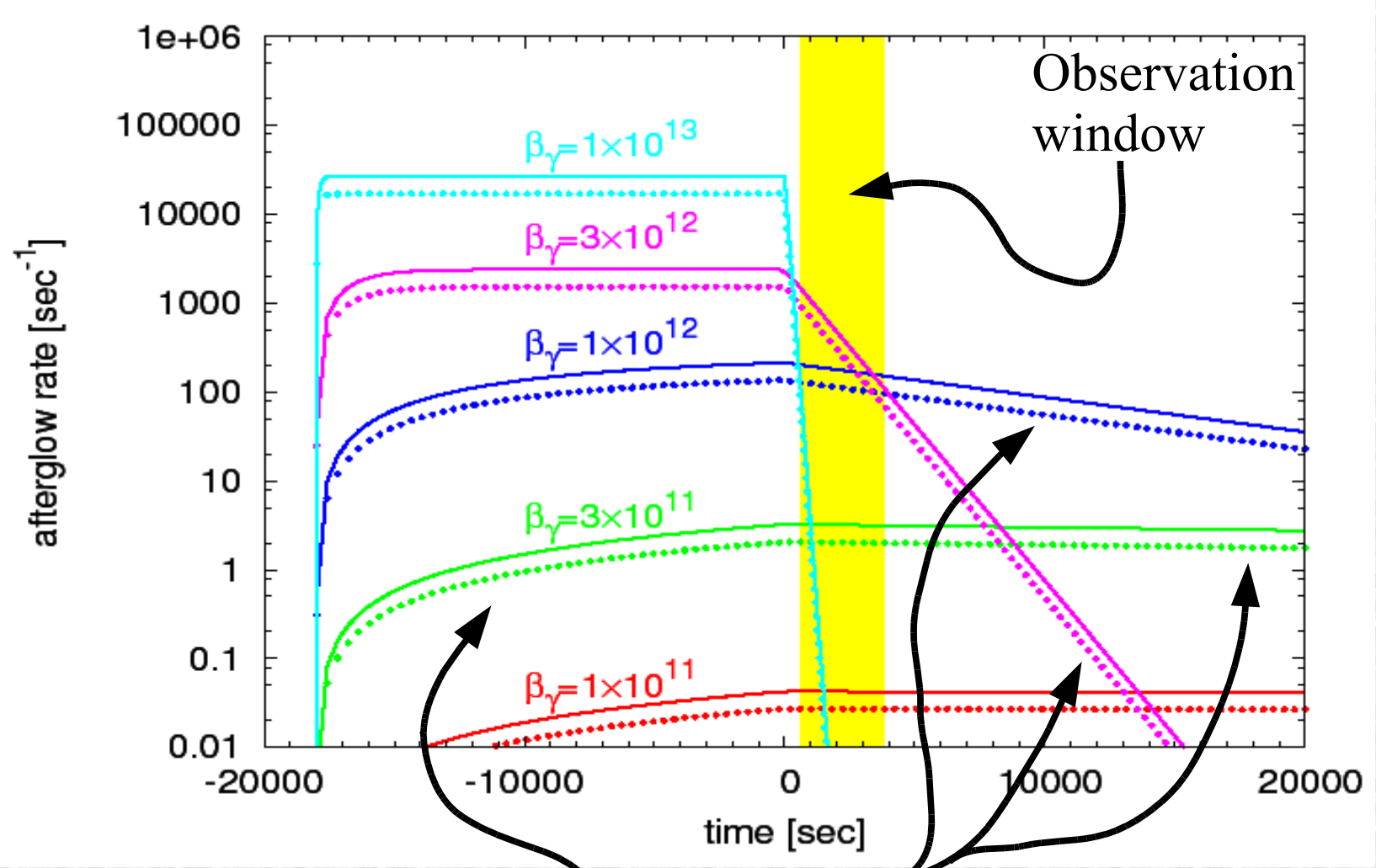

Chameleon population builds during the filling stage

Constrain coupling that are neither too large nor too small

GammeV – Chameleon: Concept

- Chameleon aspect was part of the original **GammeV** objectives
- Use existing equipment and experimental setup
- Fill the cavity for 5 hours in each of the two polarizations
- Collect data for 1 hour in each of the two polarizations

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Important Assumptions

- Chameleon self-scattering is negligible and they do not decay into lighter particles over the course of the experiment
- Chameleon particles must reflect off of all solid surfaces and the region between the vacuum pumps
- Chameleon particles cannot stick to the walls

GammeV – Chameleon: Results

Configuration	Fill Time (s)	# photons	Vacuum (Torr)	Observation (s)	Offset (s)	Mean Rate (Hz)
Pseudoscalar	18324	2.39e23	2e-7	3602	319	123
Scalar	19128	2.60e23	1e-7	3616	1006	101

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Bouncing trajectories give model dependent regeneration rates

- Assume maximal photon conversion for upper limit on photon coupling (photons escape before observation)
- Assume minimal photon conversion for lower limit on photon coupling (photon rate below detection threshold)

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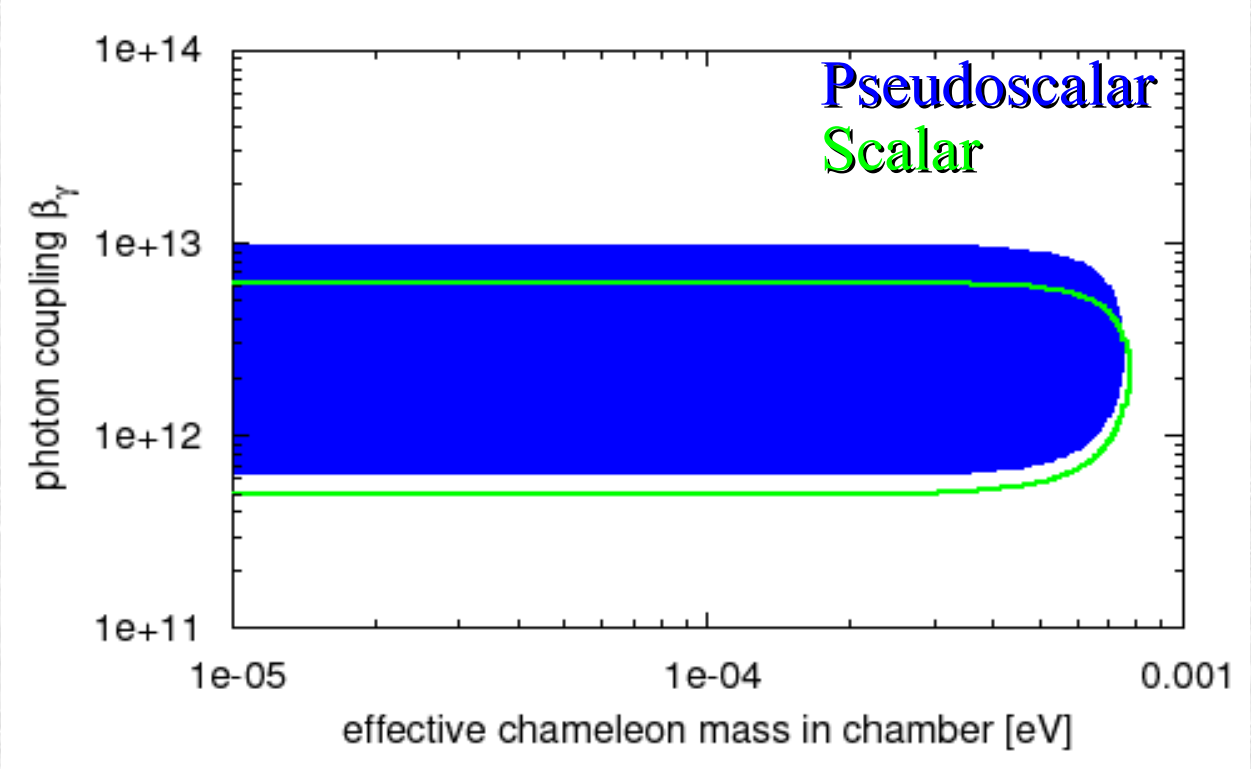
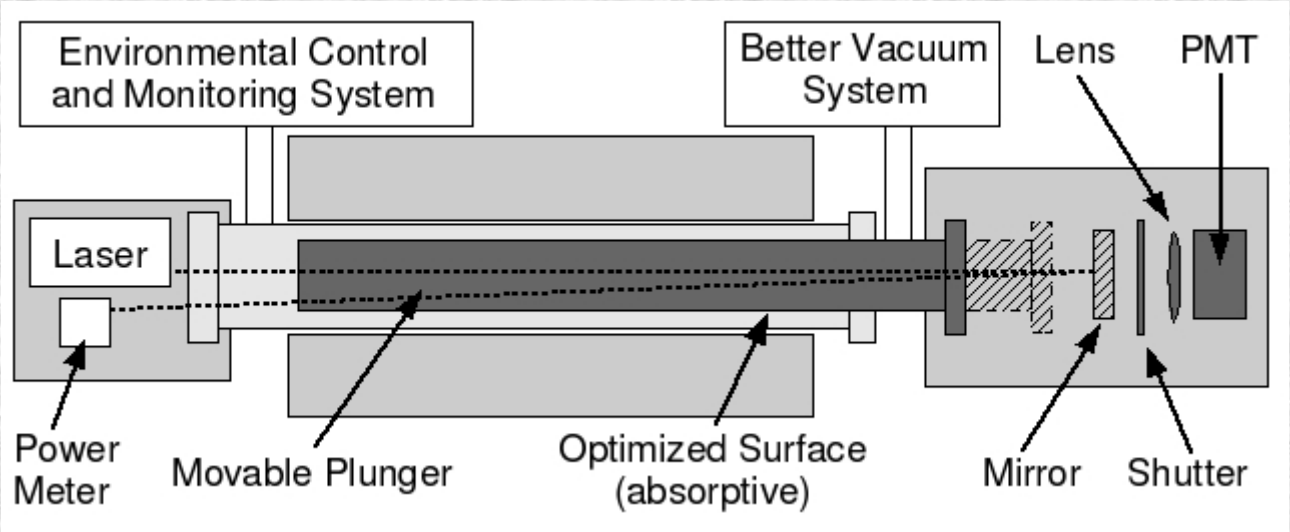
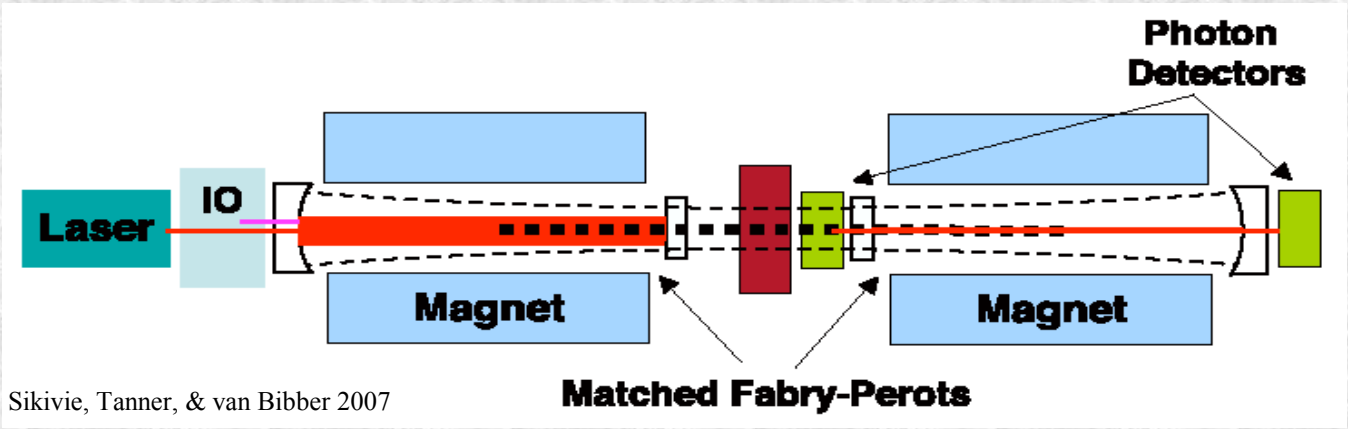


Detector systematic uncertainty dominates; we exclude models which would produce signals larger than 36Hz for $\alpha \gtrsim 0.8$.

GammeV – Plans for the future

Improved chameleon afterglow experiment.





Sikivie, Tanner, & van Bibber 2007

Resonantly enhanced LSW experiment.

Conclusions

- **GammeV** Axion search excludes the particle interpretation of the PVLAS signal at more than 5-sigma.
  - Variable baseline and pulsed laser are key aspects of the experiment

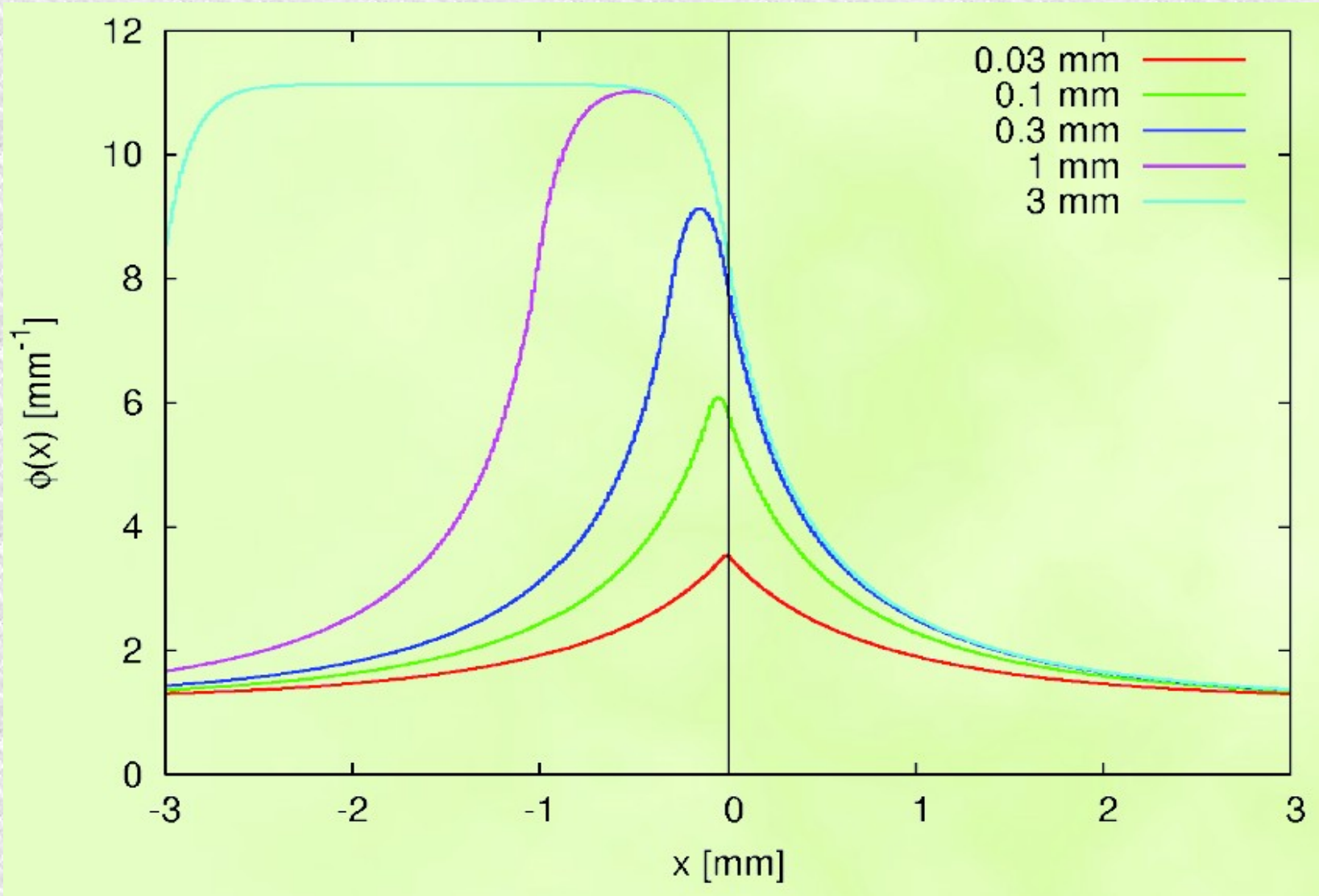
- **GammeV** Chameleon search can probe interesting chameleon models
  - First application of the particle-in-a-jar method

- Improved experiments for both axions and chameleons are under development.

Axion results: PRL 100, 080402, (2008). arXiv:0710.3783
Chameleon results: PRL Submitted (2008). arXiv:0806.2438

Chameleon Particles

Evades short-range tests of gravity via “thin shell” mechanism



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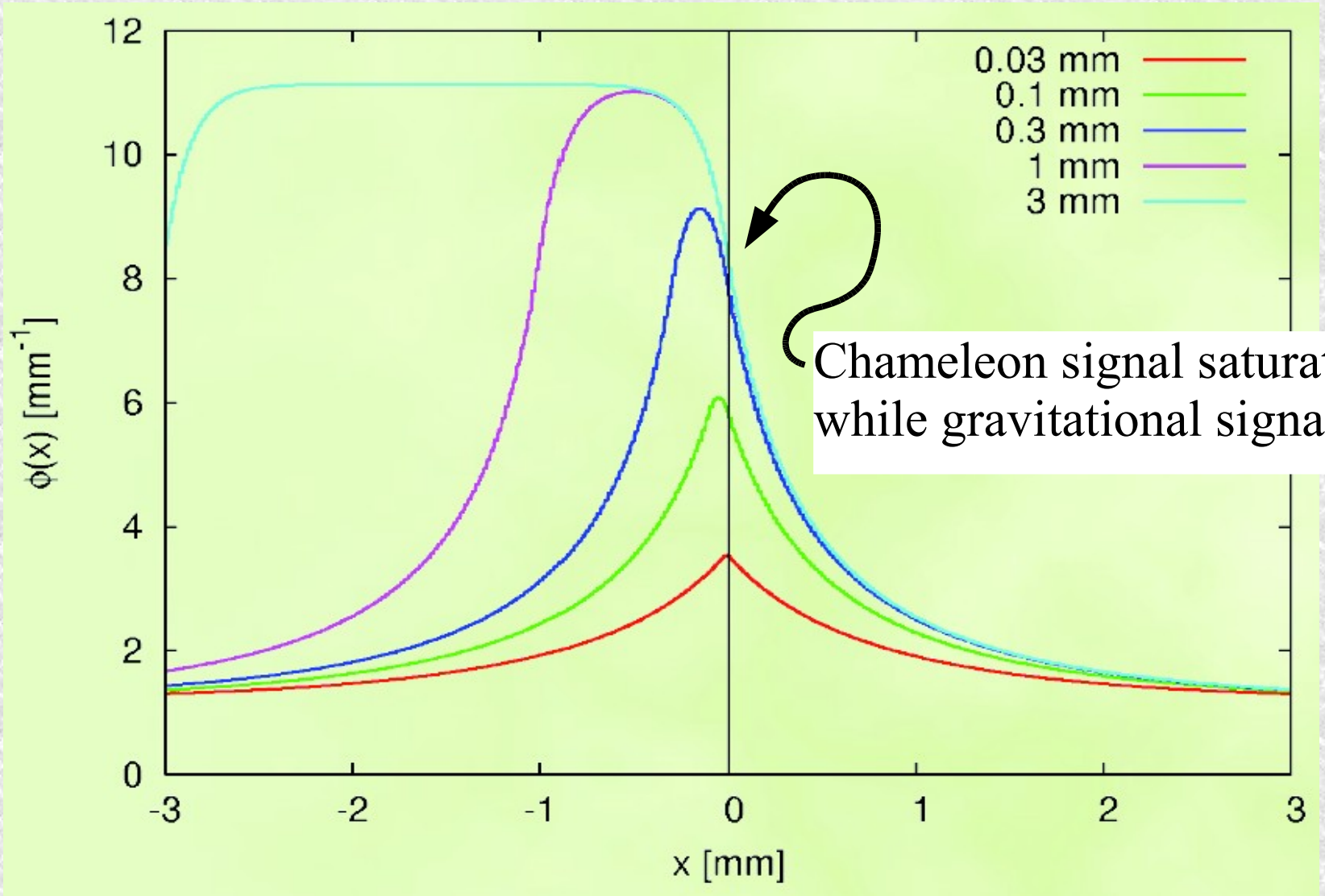
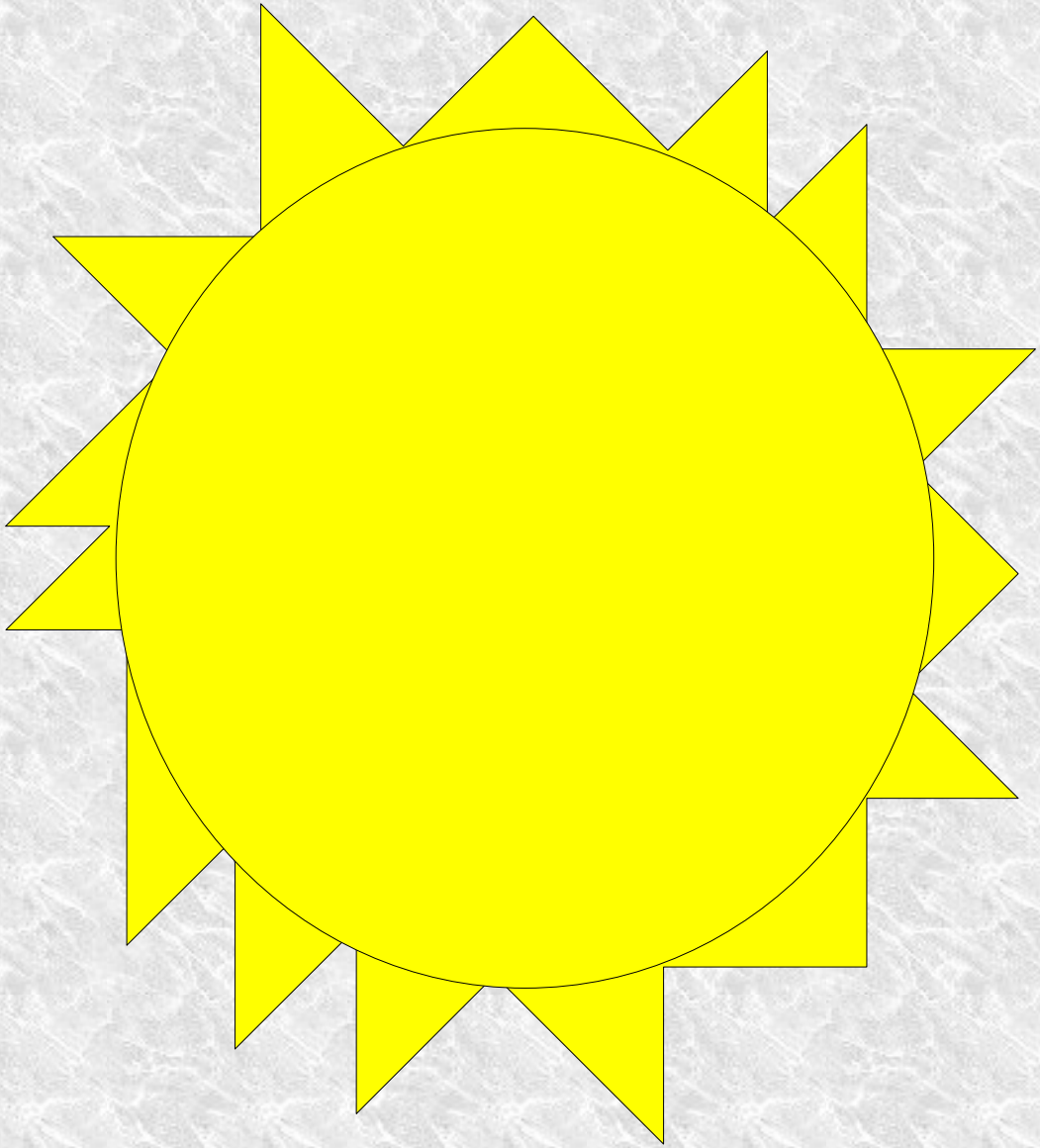


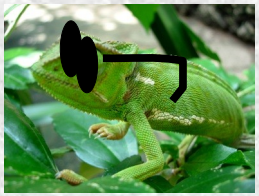
Chameleon signal saturates while gravitational signal grows.

Chameleon Particles

Evades star cooling limits due to large mass in stellar environment



I could live here



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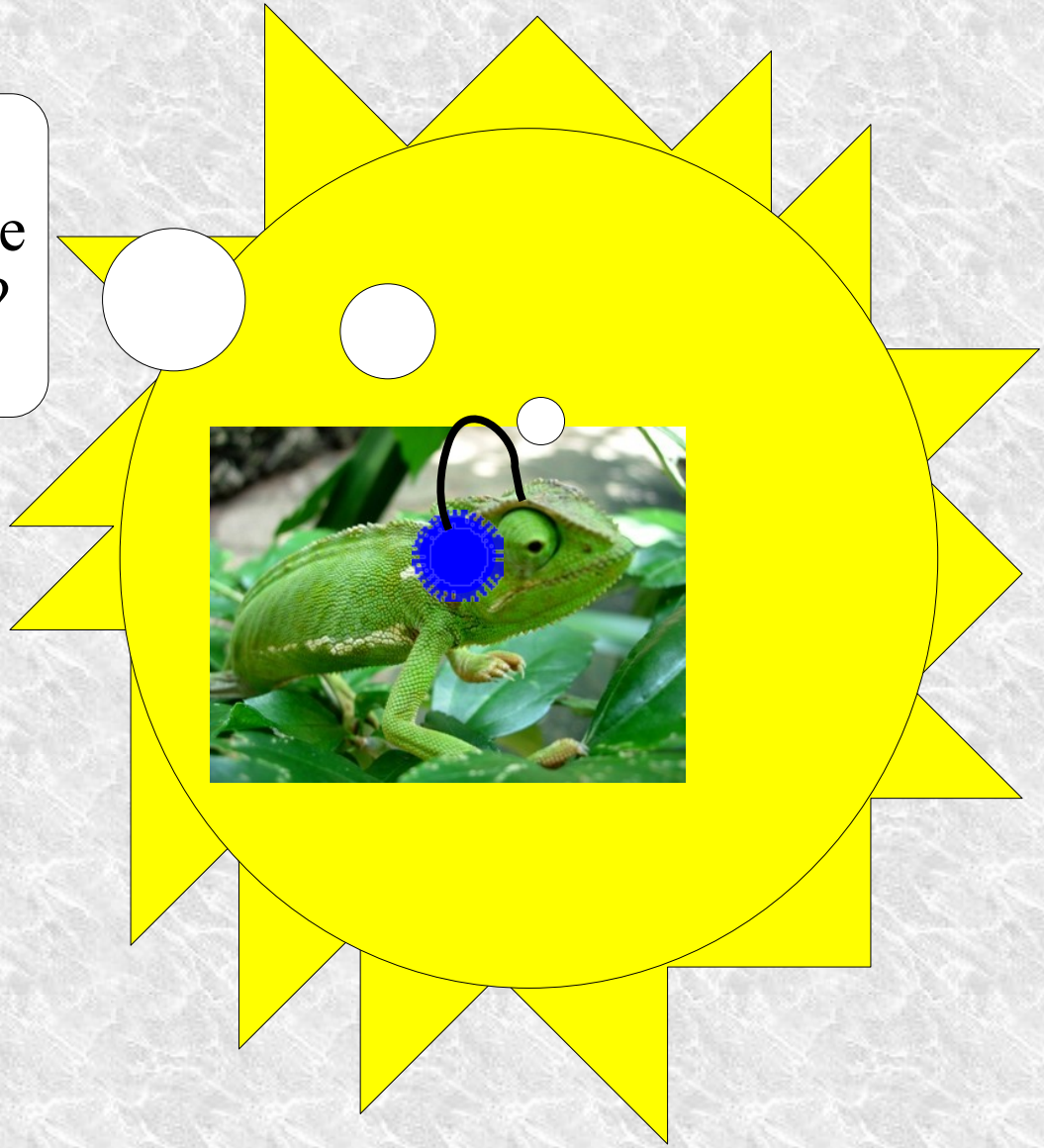
This is so cold why would anyone want to live here?



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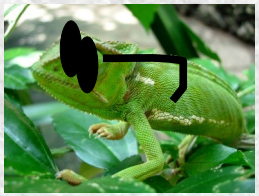
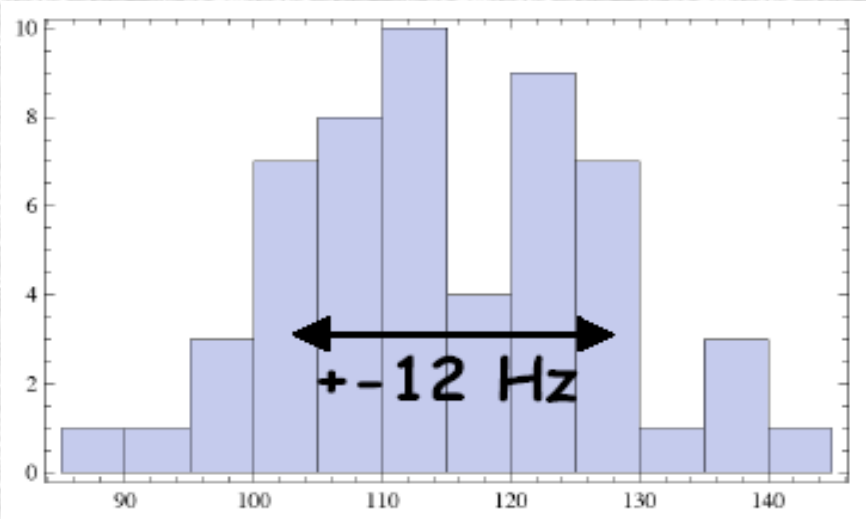
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